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A Program and Documentation for

Simulation of a Rubber-Tired Feller/Buncher

Sharon A. Winsauer and Dennis P. Bradley

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Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate and study the productivity and in-woods operation of a rubber-tired feller/buncher.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.

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A PROGRAM AND DOCUMENTATION FOR SIMULATION OF A RUBBER-TIRED FELLER–BUNCHER

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Computer modeling of forest harvesting systems has many applications, each requiring a different approach to simulation. Simulations range from technical descriptions of the machine components for equipment design to overviews of large systems where the model estimates the changes in productivity caused by major system changes. The Forestry Sciences Laboratory personnel at Houghton, Michigan, have been developing harvesting simulators as a forest engineering research tool for several years (Bradley *et al.* 1976; Bradley and Winsauer 1976, 1978; USDA Forest Service 1978; Winsauer 1980).

The purpose of this paper is to document a computer model for a rubber-tired, frame-steered feller/buncher (fig. 1). The model was developed to provide a detailed study of the machine's operation in the woods during felling and bunching. It allows the user to determine cost and productivity under various stand and harvest conditions, ways to increase machine efficiency, or to study the effect of changing harvest patterns on cost and productivity Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

THE EQUIPMENT STUDIED

The feller/buncher simulated is a rubber-tired frame-steered chassis with a shear mounted on the front. The shear accumulator can hold one or more trees, but the machine must drive up to each tree to fell it.

MODEL OBJECTIVES

The primary objective of this model is to allow a detailed study of the productivity and operation of the feller/buncher in the woods. For input, the model requires data on the machine's operating characteristics, the stand, and the type of harvest to be carried out.

After simulating the harvest of a plot, the model reports productivity figures such as: trees, tons and volume per hour and per load, total cycles, tree per cycle, distance traveled, and skid bunches completed.

Additional output gives details of the woods operation, distributions of cycle times, distances, number of trees per bunch, size of skidder bunches, frequency and length of delays, etc.

SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation Language (GPSS) with output subroutines written in FORTRAN. GPSS is a discrete event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up from a group of specific GPSS block types. These blocks then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Figure 1.—*Typical rubber-tired type feller/buncher.*

Most versions of GPSS have a standard output format that contains allthe data in a very concise form. The FORTRAN subroutines are used to present the output values of most interest in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a centiminute; i.e., 1/100 of a minute. The feller works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot.

It is assumed that the feller/buncher operates in an area far enough in advance of the skidder to minimize interactions between machines. To simulate a hot logging operation, this model can be combined with a complete skidding-chipping or skidding-loader model. Another alternative would be to add a "black box" skidder segment, a simplified segment, used to create the machine interactions without providing a detailed study of the skidder operation.

Since an efficient skidder load usually contains more trees than the shear can hold, the feller/buncher may shear and drop several loads at one location to create the skidder bunch.

The following assumptions are made about the feller/buncher's behavior:

1. A feller/buncher cycle is defined as starting after a load is dropped and ending when the next load is dropped.
2. The machine has an accumulating shear. (The model can easily be changed to single head shear by limiting the accumulator load to one.).
3. The feller/buncher must move up to each tree to shear it. It travels back and forth across a relatively narrow strip of forest, cutting trees marked for cutting as it encounters them, working its way along the trip until the far end of the plot is reached. It then moves to the next strip and repeats the process (fig. 2).
4. The feller will cut and accumulate multiple trees before dropping them. It will drop the accumulator head load when the accumulator head is full or if the next tree to cut is too far away.
5. When the feller must drop the trees held in the accumulator head, it will carry the load to the partial bunch and drop the trees there. If no partial skidder bunch has been started or if the partial bunch is judged to be too far away, it will drop them at the location of the last tree cut.

Figure 2.—*Feller/buncher travel pattern.*

6. The feller/buncher operator can quit for the day or stop for a break only after dropping the trees in the accumulator head.
7. Mechanical and nonmechanical delays for the feller are also incorporated into the model. For ease of programming, they are assumed to occur in a cycle after the feller/buncher drops the current load of trees.

MODEL DESCRIPTION

The model consists of two GPSS segments:

1. TIMER SEGMENT
2. FELLER/BUNCHER SEGMENT

and two FORTRAN subroutines for formatted (easily read) output.

The TIMER SEGMENT (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines to produce the formatted output. The TIMER signals the start of the day, the rest breaks and lunch (two 15-minute breaks a day and ½-hour lunch are assumed), and the end of the workday. The TIMER then completes the 24-hour day and produces an output report of the previous day's operation and production. Output is produced at the end of 24 hours, not at the end of the shift, to include the time needed for the feller to complete the bunch being worked on before quitting for the day. If the required number of days have been simulated, the model shuts off. Otherwise, the start of another workday is signaled, and the process continues.

The FELLER/BUNCHER SEGMENT (fig. 4) models a rubber-tired, frame-steered feller/buncher with an accumulating head shear mounted on the front. The machine must move up to each tree to cut it.

It moves through the woods along a strip but travels back and forth within the strip in order to reach the trees to be cut. The feller/buncher attempts to create bunches large enough to be skidded economically.

DATA NEEDS

GPSS accepts machine and stand data in several forms (table 1). For additional information on data types and card formats, see a GPSS Programming Manual (Schriber 1974).

Most of the data required in the main program are expected in the form of GPSS VARIABLES. These VARIABLES are then defined at the end of the deck in terms of the available machine and stand data.

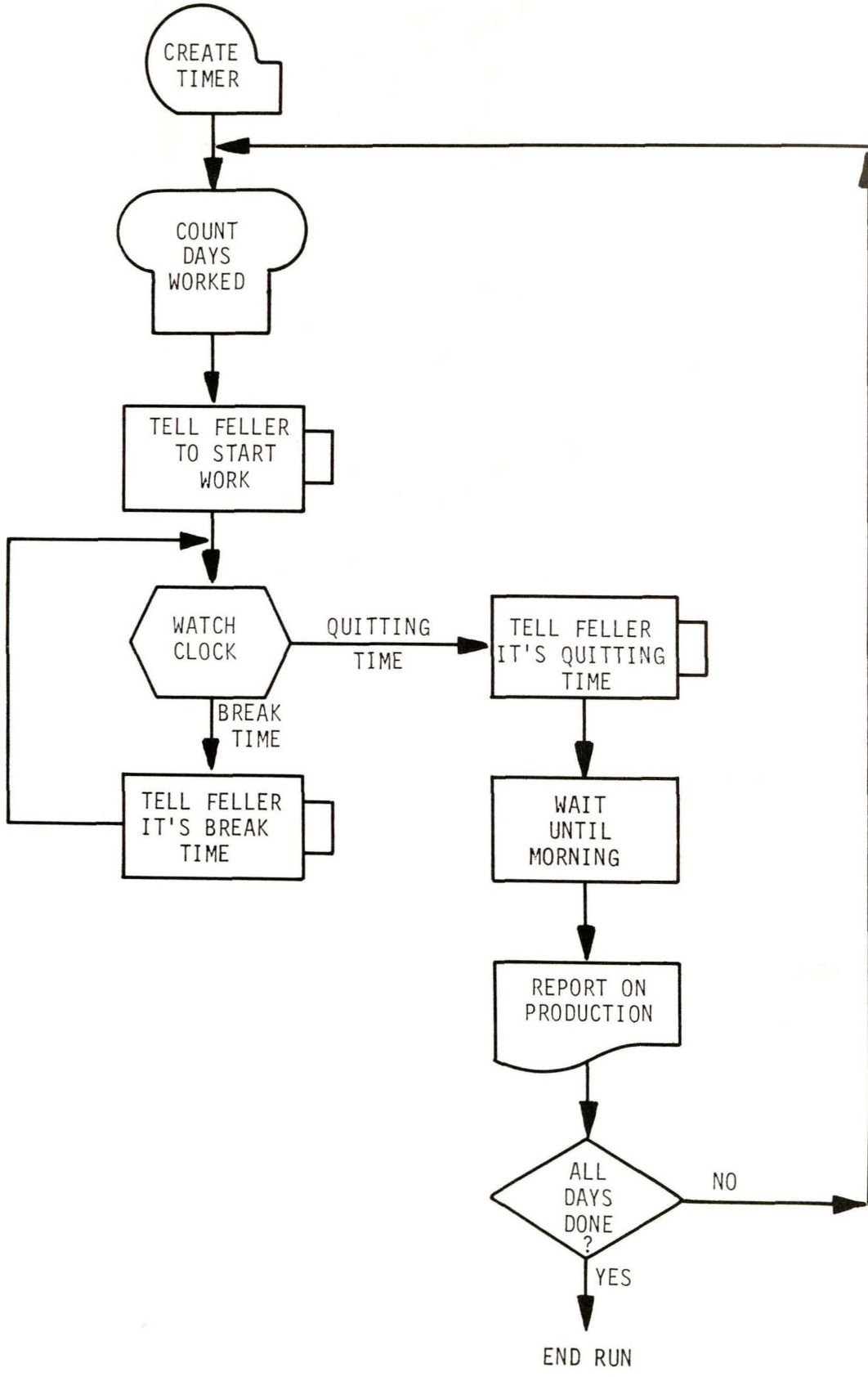

Figure 3.—*Timer segment—overview.*

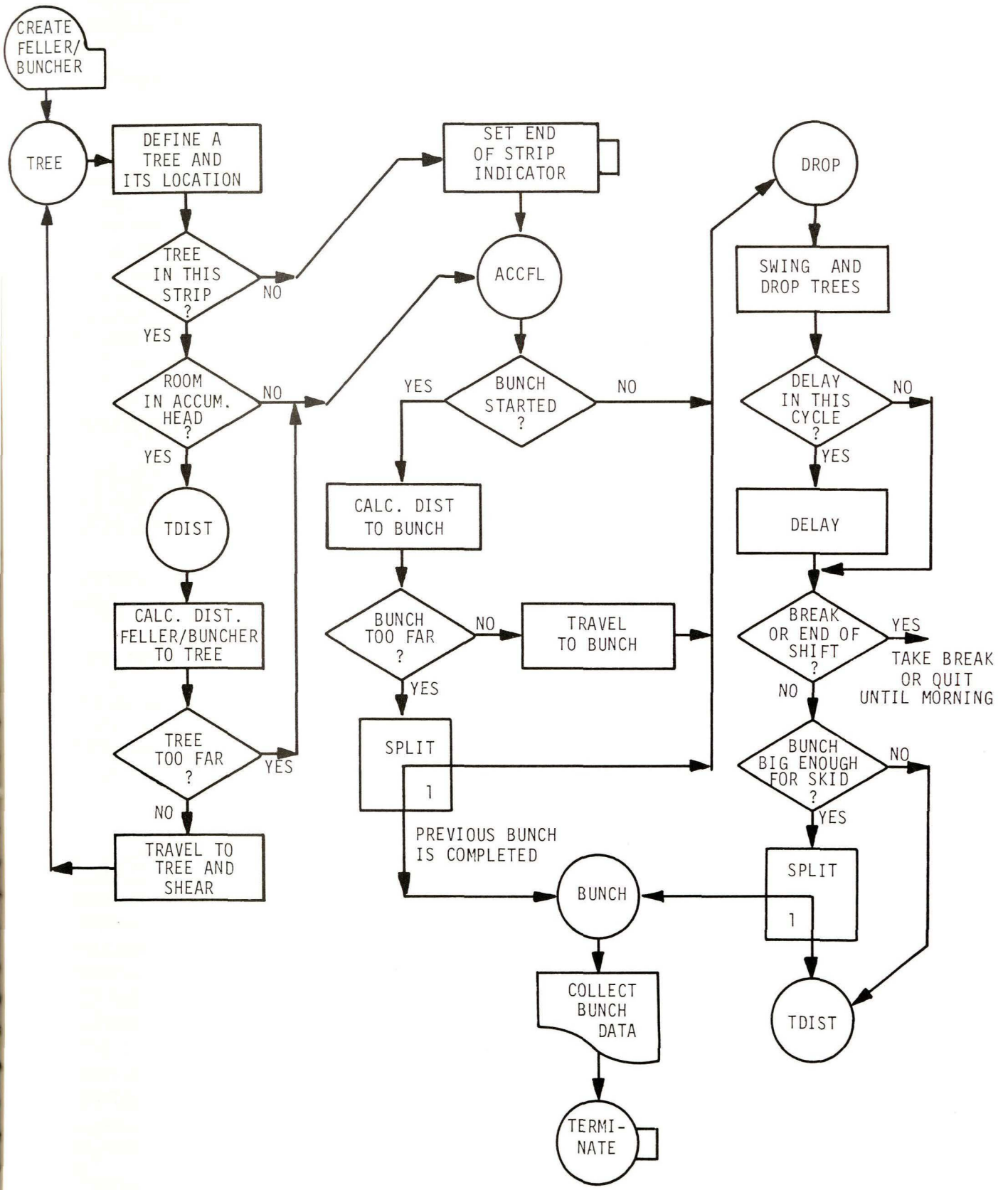

Figure 4.—*Feller/buncher segment—overview.*

Table 1.—*PSS data input forms*

Input data type	Input form in GPSS	Example
Simple averages or constants	Initialized SAVEVALUES	Ave d.b.h. = inches
Range of values	Initialized SAVEVALUES for mean and ½ width of interval	Shear Time = 10 to 14 c min = 12 ± 2 c min
Equations	VARIABLES	Volume = .13 d.b.h.^{2} − .28
Frequency distributions	FUNCTIONS	D.B.h. (in.) 4 | 5 | 6 | 7 | 8 Percent trees 23 | 25 | 30 | 15 | 5
Mean and variance for a standard distribution such as normal, poisson exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with mean = 10 variance = 9

This allows the user flexibility in data form while avoiding card shuffling in the main program For example, changing a shear time from a constant (GPSS SAVEVALUE) to a frequency distribution (GPSS FUNCTION) is accomplished by simply redefining the shear time VARIABLE and supplying the appropriate cards .

The input data cards follow the VARIABLE definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition. An exception to this convention is the use of GPSS SAVEVALUES (constants) merely for summary purposes (average stand d.b.h., average tree height, etc.).

Four types of data describing the equipment and harvesting operation must be supplied.

1. Stand data (table 2).
2. Machine data dependent upon stand conditions (table 3).
3. Machine data (independent of stand) (table 4).
4. Simulation run control (table 5).

The output example presented in this paper uses the information in tables 2 through 5 as input. These data were gathered from time studies carried out during Forest Service case studies. The data in the tables are empirical, so they represent the operating characteristics of this machine under the stand conditions found during the time studies. Different harvest conditions may require new time study data.

SIMULATION OUTPUT

The simulation run produces two pages of formatted output for each day of the run (figs. 5 and 6). These present a summary of the stand data and a cumulative productivity report.

Additional, standard GPSS output is produced at the end of the run by the GPSS processor and supplies complete run details (fig. 7).

The first page of the standard output presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is of primary value while debugging the model. The listing of the QUEUE sta-

Table 2.—*Stand data*

Data required	Case study	Form required by program	Name
Average stand diameter	5.1 in d.b.h.	SAVEVALUE	X$AVDBH
Average stand volume	2,842 cu ft./acre	SAVEVALUE	X$AVVOL
Average tree height	60 ft	SAVEVALUE	X$AVHGT
Average trees/acre	550 trees/acre (all sizes)	SAVEVALUE	X$TRPAC
Strip length	660 ft	SAVEVALUE	X$STPLN
Distance between strips	32 ft	SAVEVALUE	X$MVSTP
Density of wood	55 lb/cu ft	SAVEVALUE	X$LBCFT
Hours in daily work shift	8 hours	SAVEVALUE	X$WKDAY
Actual tree diameter	Diameter distribution	SAVEVALUE	V$TDIAD
	d.b.h. (in.) 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20		
	Percent trees 25.4 | 22.5 | 30.4 | 8.6 | 6.3 | 3.2 | 2.0 | 1.1 | .4 | .2		
Volume of trees	Volume of trees (cu ft)	VARIABLE	V$TVOL
	Volume = −0.283 + 0.0031 (d.b.h.^{2}) tree height = −0.283 + 0.186 (d.b.h.^{2})		

Table 3.—*Machine data dependent on stand conditions*

Date required	Case study	Form required by program	Name
Expected X coordinate of the next tree to be cut	X coordinate equally likely to fall anywhere in the strip X coordinate = strip width X (Rand #1) + 1	VARIABLE	V$XCORD
Expected Y coordinate of the next tree to be cut[1]	Distribution of the difference in feet (next tree's Y coordinate—current tree's Y coordinate)	VARIABLE	V$YCORD

Y DIF	0	2	4	6	8	10	12	14	16	18
Percent trees	18	30	16	12	8	4	4	3	3	2

Maximum distance feller will travel to add another tree to accumulator head	8 feet	SAVEVALUE	X$ADLIM
Maximum distance feller will travel to add additional trees to a partial bunch	45 feet	SAVEVALUE	X$BDLIM

[1]The empirical distribution of the expected location for the next tree to be cut could be replaced with an analytic function (Bradley, Dennis P. An analytical procedure to locate trees for simulated tree harvest, (manuscript in process).

Table 4.—*Machine data*

Data required	Case study	Form required by program	Name
Travel time (based on distance)	Travel speed Mean = 150 ft/min St. dev. = 50 ft/min	VARIABLE	V$FBTRAV
Shear time per tree	Shear time Mean = 25 centi-min St. dev. = 12 centi-min	VARIABLE	V$FBSHR
Drop time per load	Drop time Mean = 15 centi-min St. dev. = 9 centi-min	VARIABLE	V$FBDRP
Maximum size of skidder bunch the feller creates (sum total of diameters)	Bunch diameter limit 45 inches	VARIABLE	V$BUNLM
Gal/hr fuel used	4.7 gal/hr	SAVEVALUE	X$FBGPH
Length of nonmechanical delay per cycle (including cycles with zero delay)	Distribution of nonmechanical delays (min)	VARIABLE	V$NMDLY

LENGTH OF DELAY	0	0-1	1-2	2-5	5-10	10-20	20-50
Percent of cycles	97.3	.9	.5	.5	.4	.3	.1

Length of mechanical delay per cycle (including cycles with zero delay)	Distribution of mechanical delay (min)	VARIABLE	V$MCDLY

LENGTH OF DELAY	0	0-5	5-10	10-50
Percent of cycles	99.4	.2	.2	.2

Table 5.—*Simulation run control*

Data required	Case study	Form required by program	
Random number generators:	Random number	Use	RMULT card
	1	for GPSS scheduler	
	2	generate normal random distribution	
	3	tree location distribution	
	4	d.b.h. distribution	
	5	not used	
	6	delay distributions	
Number of days	5 days		
Standard output	every 5th day		Start card

tistics provides detailed information on how the feller/buncher spends its time in the woods. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used .

Example:

FBHR = 4,006 = feller hours × 100
FBTRE = 3,785 trees cut
3,785/40.06 × 94.48 trees/hour

```
                    FULL  TREE  FIELD  CHIPPING  SIMULATOR

                                DEVELOPED  BY  THE
                  NORTH CENTRAL FOREST  EXPERIMENT  STATION
                FOREST  SERVICE, U. S. DEPT.  OF  AGRICULTURE

          FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                AND  THE
                     FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN

                                AUTHORS
                          DENNIS P. BRADLEY, ECONOMIST
                          SHARON A. WINSAUER, PROGRAMMER


 STAND CHARACTERISTICS,

  2842.00 CU FT, AVERAGE VOLUME PER ACRE,
     5.10 INCHES, AVERAGE DBH,
    60.00 FEET, AVERAGE TREE HEIGHT,
   550.00 AVERAGE NUMBER OF TREES PER ACRE,
     8.90 FEET, AVERAGE TREE SPACING,

.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST,
A,  FELLER-BUNCHER,                    1  MACHINE      RUBBER-TIRED TYPE
      MACHINE LIMITATIONS,
        THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN A LOAD OF UP TO   5.0 TREES
      BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:
        THE FELLER-BUNCHERS TRY TO ACHIEVE SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO 120.0 IN
```

Figure 5.—*Simulation output—system and stand characteristics.*

```
   F E L L E R - B U N C H E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y
**********************************************************************************************************************************

I.    A.    40.06     HOURS WORKED BY FELLER-BUNCHER INCLUDING
                298.00     MINUTES OF PERSONAL BREAKS,
                223.50     MINUTES MECHANICAL DELAY,
                178.80     MINUTES NON-MECHANICAL DELAY
      B.        1      FELLER-BUNCHER,     RUBBER-TIRED TYPE,

II.   A.     1490      TOTAL ACCUMULATOR CYCLES COMPLETED - ALL MACHINES,
                2.54     AVERAGE NUMBER OF TREES PER CYCLE,
               20.76     AVERAGE VOLUME PER CYCLE - CU.FT,
      B.      348      BUNCHES COMPLETED
               10.88     AVERAGE NUMBER OF TREES PER BUNCH,
                4.28     AVERAGE NUMBER OF CYCLES PER BUNCH,
               88.87     AVERAGE VOLUME PER BUNCH - CU.FT,
      C.     3785      TOTAL TREES FELLED,
      D.  30927.3      TOTAL VOLUME FELLED - CU.FT,
      E.   850.50      TOTAL TONS FELLED
      F.    77027      TOTAL DISTANCE TRAVELED - FEET

III.  A.    37.19      AVERAGE NUMBER OF CYCLES PER MACHINE HOUR,
      B.     8.69      AVERAGE NUMBER OF BUNCHES COMPLETED PER MACHINE HOUR,
      C.    94.48      AVERAGE NUMBER OF TREES FELLED PER MACHINE HOUR,
      D.   772.02      AVERAGE VOLUME FELLED PER MACHINE HOUR,
      E.    21.23      AVERAGE NUMBER OF TONS FELLED PER MACHINE HOUR,
      F.  1922.79      AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET,

IV.   A.   188.28      TOTAL GALLONS OF FUEL USED BY THE FELLER-BUNCHER,
                4.70     GALLONS PER HOUR,
                 .22     GALLONS PER TON,
                 .61     GALLONS PER CUNIT,
```

Figure 6.—*Simulation output—productivity.*

*** GPSS/X8 NORMAL COMPLETION OF SIMULATION RUN ***

RELATIVE CLOCK: 720001 ABSOLUTE CLOCK: 720001

TRANS COUNT:

BLOCK	TRANS, TOTAL	BLOCK	TRANS, TOTAL	BLOCK	TRANS, TOTAL	BLOCK	TRANS, TOTAL	BLOCK	TRANS, TOTAL
TIMER	0, 1	NXDAY	0, 5	3	0, 5	DAY	0, 5	5	0, 5
6	0, 5	7	0, 5	8	0, 5	9	0, 5	10	0, 5
11	0, 5	12	0, 5	13	0, 5	14	0, 5	15	0, 5
16	0, 5	17	0, 5	18	0, 5	19	0, 5	20	0, 5
21	0, 5	22	1, 10	OUTPT	0, 5	ACCFB	0, 1	INIT	0, 1
26	0, 1	27	0, 1	28	0, 1	29	0, 1	30	0, 1
TREE	0, 3786	32	0, 3786	33	0, 3786	34	0, 3786	35	0, 3786
36	0, 27	37	0, 27	38	0, 27	OLDST	0, 3759	TDIST	0, 4964
41	0, 4964	42	0, 2264	UTST1	0, 4964	44	0, 4964	45	0, 0
DTST2	0, 4964	47	0, 4964	48	0, 4964	49	0, 3015	50	0, 3015
DTST3	0, 4964	52	0, 4964	53	0, 3871	FIRST	0, 4964	55	0, 3474
FELL	0, 3785	57	0, 3785	58	0, 3785	59	0, 3785	60	0, 3785
61	0, 3785	62	0, 3785	63	0, 3785	64	0, 3785	65	0, 3785
66	0, 3785	67	0, 3785	68	0, 3785	69	0, 3785	70	0, 3785
ACCFL	0, 1490	72	0, 1457	73	0, 1457	74	0, 629	DTSTA	0, 1457
76	0, 1457	77	0, 1445	DTSTB	0, 1457	79	0, 1457	80	0, 1457
81	0, 1374	82	0, 1374	DTSTC	0, 1457	84	0, 1457	85	0, 1304
PBFAR	0, 1457	87	0, 316	88	0, 632	89	0, 316	90	0, 316
91	0, 316	TRVPB	0, 1141	93	0, 1141	94	0, 1141	95	0, 1141
96	0, 1141	97	0, 1141	DROP	0, 1490	99	0, 1490	100	0, 1490
101	0, 1490	102	0, 1490	103	0, 1490	104	0, 1490	105	0, 1490
106	0, 1490	107	0, 1490	108	0, 1490	109	0, 1490	110	0, 1490
111	0, 1490	112	0, 1490	113	0, 1490	114	0, 1490	115	0, 10
116	0, 10	NOBRK	0, 1490	118	0, 5	119	0, 5	QUIT	0, 1490
121	0, 1490	122	0, 1490	123	0, 1490	124	0, 1490	125	0, 1490
126	0, 1489	127	0, 1489	128	0, 1489	129	0, 1489	130	0, 1489
131	0, 1489	132	0, 1489	133	0, 1489	134	0, 1489	135	0, 1484
BNCOM	0, 32	137	0, 64	138	0, 32	139	0, 32	140	0, 32
141	0, 27	142	0, 27	143	0, 27	144	0, 27	BUNCH	0, 348
146	0, 348	147	0, 348	148	0, 348	149	0, 348	150	0, 348
151	0, 348	152	0, 348	153	0, 348	154	0, 348	155	0, 348
156	0, 348	157	0, 348						

CURRENT EVENTS CHAIN

TRANS	BDT	BLK	PR	NBA	MARKTIME	SET	SDIP	PARAMETERS											
284	720001	23	12	24	1	355		0	0	0	0	0	0	0	0	0	0	0	0
355	0	22	12	2	1	284		0	0	0	0	0	0	0	0	0	0	0	0
2	624114	125	10	126	1	2	11	0	623995	7	62	3786	5	94	6	24	0	11	826
								3	0	0	0	0	0	0	0	0	0	0	0

FUTURE EVENTS CHAIN

TRANS	BDT	BLK	PR	NBA	MARKTIME	SET	SDIP	PARAMETERS

QUEUE STATISTICS

QUEUE NR	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$ AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
BREAK	1	.04	1490	1475	99.0	20.13	2000.00	0	0
MCDLY	1	.03	1490	1477	99.1	15.42	1766.92	0	0
NMDLY	1	.02	1490	1449	97.2	12.01	436.37	0	0
FBTRV	1	.07	4926	239	4.9	10.94	11.50	0	0
FBSHR	1	.13	3785	0	0.0	24.74	24.74	0	0
FBDRP	1	.03	1490	0	0.0	14.75	14.75	0	0

*** NO GROUPS WERE USED ***

SAVE VALUES

SAVEX

NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE
WKDAY	8	DAYS	5	FBHR	4006	BRKTM	29800	DELYA	22350
DELNM	17880	FBTIM	240391	AVVOL	284200	AVDBH	510	AVHGT	60
TRPAC	550	NUMFB	0	ACLM1	5	FBTYP	1	BNLM1	120
FBTRE	3785	FBVOL	3092727	BNCOM	348	FBDIS	77027	FBACC	1490
LBCFT	55	FBGPH	47	MAX	24	MIN	4	STPLN	660
PBX	7	PBY	62	XDIF	4	YDIF	24	ACCLM	5
RUNLM	120	ADLIM	8	PBDIA	31	BDLIM	45	PBTRE	6
PBEND	0	PBVOL	3307	MVSTP	32	FTRV1	150	FTRV2	50
FSHR1	25	FSHR2	12	FDRP1	15	FDRP2	9	STPWH	10

*** NO MATRICES WERE USED ***

Figure 7.—*Simulation output—standard GPSS form*

Additional details of the in-woods operations are provided by the GPSS TABLES (figs. 8-10). The cycle time table FBTIM (cycle time starts after the feller/buncher drops one load and ends when it drops the next) shows there were 1,490 cycles with an average cycle time of 161 centi-minutes. Of all 1,490 cycles, 240 cycles or 16 percent took between 100 and 125 centi-minutes .

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves a random sample of what could happen. If the model is run again with different random samples, the exact results will be different but will reflect the underlying means and variance of the system. An average over several days or several runs is the best estimate of an actual system .

RELIABILITY

The simulation described here used data obtained in a previous study of mechanized thinning. Three simulation runs were made using different random number sequences to insure different random samples. Simulated production figures were averaged and compared with the productivity observed during the actual thinning (table 6). The greatest error of 14.7 percent appears in cycles/hour with delay. A portion of this error can be attributed to the simulation runs having a higher percent of productive time on the runs made. Other runs, with different random number sequences, would alter the number and duration of delays, hence the cycles/hour. The comparison indicates the model is a reasonably accurate mirror of the real system. Obviously, the better the input data, the more useful the output!

KNOWN GPSS SYSTEMS DIFFERENCES

The program listed in the Appendix is operational on a UNIVAC 1110 under an implentation of GPSS called GPSS-X8, obtained through Use Program Library Interchange (UPLI). It should run under most GPSS Processors with only minor changes. The following should be checked for your system.

INITIAL cards—In GPSS-X8, the INITIAL cards appear last in the deck.
They should be moved to the head of the deck for most other GPSS processors.

JOB CONTROL cards—These are unique to each computer lab and must be obtained locally.

HELP BLOCKS—In GPSS-X8, HELP BLOCKS (line 65-80 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted, the subroutine cannot pass arguments back to GPSS.

Some versions of GPSS do not allow HELP BLOCKS. In this case, the program can be run without lines 48 to 80 and the data obtained instead from the standard output. If some form of HELP BLOCKS are allowed, the HELP BLOCKS formats and the subroutines may have to be changed. See the GPSS manual for your computer installation.

CONCLUSIONS

Most harvesting system changes have relatively complex effects on productivity. The simulation model provides an in-depth look at the operation of this machine in the woods and makes it possible to study the effect of a change in any one system characteristic or stand factor or many changes at the same time. It can also be combined with a model of skidding and chipping operations to provide productivity information for a whole-tree system. Perhaps the greatest value of a GPSS model is the ease with which it can be modified to suit the exact requirements of your system. Although this requires some knowledge of GPSS, it makes simulation an extremely valuable tool.

Table 6.—*Corroboration of simulated productivity with field data*

Field data and simulated productivity	Productive time worked	Trees per hour		Cycles per hour		Average number trees	
		No delays	With delays	No delays	With delays	/Cycle	/Skidbunch
	Percent						
Field data	73	132	94	48	34	2.8	10.1
Simulation runs[1]	78	130	98	51	39	2.5	10.8
(Error)	(6.8)	(−1.5)	(4.1)	(5.8)	(14.7)	(−10.7)	(6.9)

[1]Average of three simulation trials using different random number sequences.

CYCLE TIME (CENTI-MINUTES)

TABLE FBTIM — ENTRIES IN TABLE 1490 — MEAN ARGUMENT 161.34 — STANDARD DEVIATION 324.50 — SUM OF ARGUMENTS 240391.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
25	1	.06	.0	99.9	.15	-.42
50	83	5.57	5.6	94.4	.31	-.34
75	283	18.99	24.6	75.4	.46	-.26
100	293	19.66	44.3	55.7	.62	-.18
125	240	16.11	60.4	39.6	.77	-.11
150	178	11.95	72.3	27.7	.93	-.03
175	176	11.81	84.2	15.8	1.08	.04
200	103	6.91	91.1	8.9	1.24	.11
225	54	3.62	94.7	5.3	1.39	.19
250	17	1.14	95.8	4.2	1.55	.27
275	8	.53	96.4	3.6	1.70	.35
300	6	.40	96.8	3.2	1.86	.42
325	2	.13	96.9	3.1	2.01	.50
375	1	.06	97.0	3.0	2.32	.65
400	2	.13	97.1	2.9	2.48	.73
425	1	.06	97.2	2.8	2.63	.81
500	1	.06	97.2	2.8	3.10	1.04
550	2	.13	97.4	2.6	3.41	1.20
OVERFLOW	39	2.62	100.0	.0		

VOLUME (CU. FT. x 100) PER ACCUMULATOR HEAD LOAD

TABLE ACCVL — ENTRIES IN TABLE 1490 — MEAN ARGUMENT 2075.66 — STANDARD DEVIATION 1934.37 — SUM OF ARGUMENTS 3092727.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500	295	19.80	19.8	80.2	.24	-.81
1000	274	18.39	38.2	61.8	.48	-.55
1500	182	12.21	50.4	49.6	.72	-.29
2000	157	10.54	60.9	39.1	.96	-.03
2500	122	8.19	69.1	30.9	1.20	.21
3000	92	6.17	75.3	24.7	1.45	.47
3500	79	5.30	80.6	19.4	1.69	.73
4000	58	3.89	84.5	15.5	1.93	.99
4500	52	3.49	88.0	12.0	2.17	1.25
5000	56	3.76	91.7	8.3	2.41	1.51
5500	25	1.68	93.4	6.6	2.65	1.77
6000	25	1.68	95.1	4.9	2.89	2.03
6500	13	.87	96.0	4.0	3.13	2.29
7000	17	1.14	97.1	2.9	3.37	2.55
7500	13	.87	98.0	2.0	3.61	2.80
8000	7	.47	98.5	1.5	3.85	3.06
8500	4	.26	98.7	1.3	4.10	3.32
9000	10	.67	99.4	.6	4.34	3.58
9500	1	.06	99.5	.5	4.58	3.84
10000	3	.20	99.7	.3	4.82	4.10
11000	2	.13	99.8	.2	5.30	4.61
11500	3	.20	100.0	.0	5.54	4.87

Figure 8.—*Simulation output.*

NUMBER OF TREES PER ACCUMULATOR HEAD LOAD

TABLE ACCTR — ENTRIES IN TABLE 1490 — MEAN ARGUMENT 2.54 — STANDARD DEVIATION 1.52 — SUM OF ARGUMENTS 3785.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	537	36.04	36.0	64.0	.39	-1.02
2	314	21.07	57.1	42.9	.78	-.35
3	222	14.90	72.0	28.0	1.18	.30
4	131	8.79	80.8	19.2	1.57	.96
5	286	19.19	100.0	.0	1.97	1.62

NUMBER OF TREES PER SKIDDER BUNCH

TABLE BTRE — ENTRIES IN TABLE 348 — MEAN ARGUMENT 10.86 — STANDARD DEVIATION 3.57 — SUM OF ARGUMENTS 3779.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	2	.57	.5	99.4	.09	-2.76
2	3	.86	1.4	98.6	.27	-2.20
3	8	2.30	3.7	96.3	.36	-1.92
4	11	3.16	6.9	93.1	.46	-1.64
5	16	4.60	11.5	88.5	.55	-1.36
6	20	5.75	17.2	82.8	.64	-1.08
7	26	7.47	24.7	75.3	.73	-.80
8	33	9.48	34.2	65.8	.82	-.52
9	40	11.49	45.7	54.3	.92	-.24
10	43	12.36	58.0	42.0	1.01	.03
11	41	11.78	69.8	30.2	1.11	.31
12	32	9.20	79.0	21.0	1.20	.59
13	20	5.75	84.8	15.2	1.29	.87
14	19	5.46	90.2	9.8	1.38	1.16
15	9	2.59	92.8	7.2	1.47	1.44
16	12	3.45	96.3	3.7	1.57	1.72
17	6	1.72	98.0	2.0	1.66	2.00
18	4	1.15	99.1	.8	1.75	2.28
19	1	.28	99.4	.5	1.84	2.56
20	2	.57	100.0	.0	1.93	2.84
21						

Figure 9.—*Simulation output.*

VOLUME (CU. FT. x 100) PER SKIDDER BUNCH

TABLE BVOL — ENTRIES IN TABLE 348 — MEAN ARGUMENT 8877.64 — STANDARD DEVIATION 4055.18 — SUM OF ARGUMENTS 3089420.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000	2	.57	.5	99.4	.11	-1.94
2000	5	1.44	2.0	98.0	.22	-1.70
3000	13	3.74	5.7	94.3	.33	-1.45
4000	14	4.02	9.8	90.2	.45	-1.20
5000	21	6.03	15.8	84.2	.56	-.95
6000	32	9.20	25.0	75.0	.67	-.71
7000	45	12.93	37.9	62.1	.78	-.46
8000	33	9.48	47.4	52.6	.90	-.21
9000	27	7.76	55.2	44.8	1.01	.03
10000	32	9.20	64.4	35.6	1.13	.27
11000	20	5.75	70.1	29.9	1.24	.52
12000	31	8.91	79.0	21.0	1.35	.77
13000	14	4.02	83.0	17.0	1.46	1.02
14000	18	5.17	88.2	11.8	1.58	1.26
15000	16	4.60	92.8	7.2	1.69	1.51
16000	7	2.01	94.8	5.2	1.80	1.76
17000	9	2.59	97.4	2.6	1.91	2.00
18000	1	.28	97.7	2.3	2.03	2.25
19000	2	.57	98.3	1.7	2.14	2.50
20000	4	1.15	99.4	.5	2.25	2.74
22000	1	.28	99.7	.2	2.48	3.24
23000	1	.28	100.0	.0	2.59	3.48

Figure 10.—*Simulation output.*

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APPENDIX A

VARIABLE LISTS AND DEFINITIONS

DEFINITIONS

IMPLICIT TIME UNIT—CENTI-MINUTE

Model Segments, Transactions, and Parameters

Segment 1—TIMER
- Transactions—1 time keeper
- Parameters—None

Segment 2—FELLER/BUNCHER
- Transactions—Feller/buncher
- Parameters
  - P1—not currently used
  - P2—clock time marking cycle
  - P3—current X coordinate of the feller/buncher
  - P4—current Y coordinate of the feller/buncher
  - P5—tree number being cut
  - P6—X coordinate of the tree
  - P7—Y coordinate of the tree
  - P8—tree diameter
  - P9—distance from feller/buncher to tree
  - P10—end of strip indicator
  - P11—sum of tree diameters in current accumulator load
  - P12—volume of current accumulator load
  - P13—number of trees in accumulator load

FUNCTIONS

DBH	Distribution of tree diameters in the stand
HYP	Distribution used to calculate the length of the hypotenuse of a right triangle
SNORM	Distribution used to obtain a normal distribution for sampling with a mean = 0, variance = 1, lower end truncated
YCDIF	Distribution of the distance along the strip from current tree to next tree; i.e., difference in Y coordinates
MCDLY	Distribution of the occurrence and duration of mechanical delay
NMDLY	Distribution of the occurrence and duration of nonmechanical delays

SAVEVALUES

ACCLM	Accumulator head limit of this load, number of trees
ACLM1	Accumulator head limit, maximum number of trees
ADLIM	Accumulator distance limit, maximum distance feller will travel to add another tree to load, feet
AVDBH	Mean stand diameter, inches × 100
AVHGT	Mean stand height, feet
AVVOL	Mean vol/acre, cu ft × 100

BDLIM	Bunch distance limit, maximum distance feller will travel to add trees to a partial skidder bunch, feet
BNCOM	Number of skidder bunches complete and ready for skidding
BNLM1	Maximum sum of diameter for skidder bunch size limit, inches
BRKTM	Total time spent on breaks, centi-minutes
BUNLM	Current bunch size limit—sum of diameter, inches
DAYS	Number of days worked
DELNM	Total time lost to nonmechanical delays, centi-minutes
DELYM	Total time lost to mechanical delay, centi-minutes
FBACC	Total number of feller/buncher accumulator loads
FBDIS	Total distance feller has traveled, feet
FBGPH	Feller/buncher fuel usage, gal/hr × 10
FBHR	Total time feller has worked, hours × 100
FBTIM	Total time feller has been on job, minutes × 100
FBTRE	Total trees cut
FBTYP	Feller/buncher type code, rubber-tired = 1
FBVOL	Total volume cut, cu ft × 100
FDRP1	Mean drop time, centi-minutes
FDRP2	Standard deviation drop time, centi-minutes
FSHR1	Mean shear time, centi-minutes
FSHR2	Standard deviation shear time, centi-minutes
FTRV1	Mean travel speed, ft/min
FTRV2	Standard deviation travel speed, ft/min
LBCFT	Density of stand species, lb/cu ft
MAX	Longest distance of travel (X or Y direction), ft
MIN	Shortest distance of travel (X or Y direction), ft
MVSTP	Distance feller travels between strips, ft
NUMFB	Number of feller/bunchers on job
PBDIA	Partial bunch sum of diameter, inches
PBEND	Partial bunch end of strip indicator
PBTRE	Partial bunch number of trees
PBVOL	Partial bunch—current volume, cu ft × 100
PBX	Partial bunch X coordinate
PBY	Partial bunch Y coordinate
STPLN	Length of strip, ft
STPWH	Width of strip, ft
STRIP	Number of strips harvested
TRPAC	Mean stand density, trees/acre
WKDAY	Length of work shift, hours
XDIF	Distance between the feller's current location and its next location across strip, ft
YDIF	Distance between the feller's current location and its next location along strip, ft

SWITCHES

COFFE	Set by timer to indicate coffee breaks
DAY	Set by timer to indicate beginning of workday
LUNCH	Set by timer to indicate lunch break

TABLES

ACCTR	Trees per accumulator load
ACCVL	Volume per accumulator load, cu ft × 100
BDIA	Sum of diameter of trees in skid bunch, inches
BTRE	Trees per skidder bunch
BVOL	Volume per skidder bunch, cu ft × 100
FBTIM	Cycle time for feller/buncher from drop to drop, including delays, centi-minutes

QUEUES

BREAK	Coffee and lunch break time
FBDRP	Swing and drop time
FBSHR	Position and shear time
FBTRV	All travel time
MCDLY	Mechanical delays
NMDLY	Nonmechanical delays

VARIABLES

ACCLM	Accumulator head limit, number of trees
BREAK	Time between breaks, centi-minutes
BRKTM	Time spent on breaks, centi-minutes
BUNLM	Skidder bunch limit, sum of diameter, inches
DELNM	Nonmechanical delay time, centi-minutes
DELYM	Mechanical delay time, centi-minutes
FBDRP	Swing and drop time, centi-minutes
FBHR	Total time, hours × 100
FBSHR	Shear time, centi-minutes
FBTRV	Travel time, centi-minutes
HYP	Length of hypotenuse of a right triangle
MCDLY	Length of mechanical delay
NEWY	Y coordinate when skidder changes strips
NIGHT	Remainder of 24 hours after work shift, centi-minutes

NMDLY	Length of nonmechanical delay, centi-minutes
NXDIF	Used to make distance in X direction positive
NYDIF	Used to make distance in Y direction positive
RATIO	Ratio between the legs of a right triangle
SPEED	Feller/buncher travel speed, ft/min
TDIAM	Tree diameter, inches
TVOL	Tree volume, cu ft × 100
WKDAY	Length of work shift, centi-minutes
XCORD	X coordinate (across strip) of tree location, ft
YCORD	Y coordinate (down strip) of tree distance, ft
XDIF	X distance from feller/buncher to tree
YDIF	Y distance from feller/buncher to tree
XDIF1	X distance from feller/buncher to partial bunch
YDIF1	Y distance from feller/buncher to partial bunch

APPENDIX B

PROGRAM LISTING

```
*
*          FELLER BUNCHER SIMULATOR
*               UPDATED  JAN 1981
*
*
*        U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
*        MARKETING PROJECT, DULUTH, MINNESOTA
*        ENGINEERING PROJECT, HOUGHTON, MICHIGAN
*
*          AUTHORS:  SHARON A. WINSAUER
*                    DENNIS P. BRADLEY
*
*
*
*                  MASTER TIMER AND REPORT GENERATOR
*
*
*          THIS SEGMENT CONTROLS THE STOP AND START OF THE FELLER BUNCHER,
*            THE HOURS WORKED  PER DAY, XSWKDAY, AND THE NUMBER OF
*            DAYS WORKED(ARGUMENT A ON START CARD)
*
*          IT ALSO CALCULATES OUTPUT VALUES,VALUES TO BE SENT TO HELP BLOCKS,
*
*
*
*
```

```
*
*  * * * *  STAND DATA AND MACHINE CHARACTERISTICS REPORT
*
17          HELP        SYSTM,X$AVVOL,X$AVDBH,X$AVHGT,X$TRPAC
18          HELP        SYSTM,X$NUMFB,X$ACLM1,X$FBTYP,X$BNLM1
*                    AVE VOL,AVE DBH,AVE HEIGHT,TREES/ACRE,NUM OF FELLERS
*                FB ACCUMULATOR HEAD LIMIT,FB TYPE,SKIDDER BUNCH LIMIT
*
*  * * *  FELLER BUNCHER  PRODUCTION REPORT
*
19          HELP        FELBN,X$NUMFB,X$FBTYP,X$BRKTM,X$DELYM,X$DELNM
*             NUM OF FELLER BUNCHERS, FB TYPE,BREAKTIME,DELAY TIME
*
20          HELP        FELBN,X$FBTRE,X$FBVOL,X$BNCOM,X$FBHR,X$FBDIS
*             TOT TREES,TOT VOL,SKID BUNCHES COMPLETED,FB HOURS,TOT DIST TRAVELED
*
21          HELP        FELBN,X$FBACC,X$LBCFT,X$FBVOL,X$FBGPH
*             NUM OF ACC LOADS, WOOD DENSITY LB/CUFT, TOT VOL, GAL PER HOUR USED
*
22          SPLIT       1,NXDAY
23   OUTPT  TERMINATE   1
*
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*       GENERAL FUNCTIONS NEEDED IN MODEL
*
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*  * * *  FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
*           NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
*
*         NOTE: TO AVOID DATA LOSS FROM INTERGERAZATION,
*               FUNCTION VALUES HAVE BEEN
*               MULTIPLIED BY 10
*         *  *  USE     MEAN+(FN$SNORM * S.DEV)/10
*
*         NOTE: LOWER END OF FUNCTION HAS BEEN TRUNCATED
*               TO AVOID NEGATIVE ADVANCE BLOCKS
*               WHEN STANDARD DEVIATIONS ARE LARGE
*
*
 SNORM FUNCTION   RN2,C20
0,-15/.0668,-15/.1151,-12/.1587,-10/.2119,-8/.2742,-6/.3446,-4
.4207,-2/.5,0/.5793,2/.6544,4/.7258,6/.7881,8/.8413,10/.8849,12
.9332,15/.9772,20/.9938,25/.9986,30/.9999,40/1.,50
*
*         THIS FUNCTION IS USED FOR DISTANCES FOR THE FELLER BUNCHER
*
*  * * *  V$HYP GIVES THE LENGTH OF THE HYPOTENUSE OF A RT TRIANGLE
*           WITH SIDES EQUAL TO X$MAX AND X$MIN
*
 RATIO VARIABLE   X$MAX*10/X$MIN
*
 HYP   VARIABLE   X$MAX*FN$HYP/1000
*
 HYP   FUNCTION   V$RATIO,D24
10,1414/11,1351/12,1302/13,1262/14,1229/15,1202/16,1179/17,1160/18,1144
19,1130/20,1118/22,1098/24,1083/26,1071/28,1062/30,1054/35,1040/40,1031
50,1020/60,1014/70,1010/80,1008/100,1005/20000,1000
*
*
```

```
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*  * * *  ACCUMULATING OR SINGLE STEM RUBBER TIRED FELLER BUNCHER SEGMENT
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*
*        THIS SEGMENT MODELS A RUBBER-TIRED FELLER BUNCHER WITH
*        AN ACCUMULATING SHEAR ATTACHED TO THE FRONT
*
*        THE FELLER TRAVELS FROM TREE TO TREE, CUTTING EACH
*        TREE, GENERALLY CUTTING A REASONABLY WIDE
*        SWATH OR STRIP THROUGH THE WOOD
*
*        THE FELLER COMBINES MULTIPLE ACCUMULATOR HEAD
*        BUNCHES TO OBTAIN BUNCHES LARGE ENOUGH FOR
*        THE SKIDDER.
*
*
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*                    FELLER BUNCHER PARAMATER ASSIGNMENTS
*
*            P1     NOT USED
*            P2     CLOCK TIME
*            P3     X COORD OF FELLER BUNCHER
*            P4     Y COORD OF FELLER BUNCHER
*            P5     TREE NUMBER
*            P6     X COORD OF TREE
*            P7     Y COORD OF TREE
*            P8     TREE DIAMETER
*            P9     DIST FROM FB TO TREE
*            P10    END OF STRIP INDICATOR
*            P11    SUM OF DIAMETER OF LOAD
*            P12    SUM OF VOLUME OF LOAD
*            P13    NUMBER OF TREES IN LOAD
*
*  * *     DEFINING VARIABLES FOR FELLER BUNCHER
*
*
 NEWY   VARIABLE   P7-X$STPLN              NEW Y CORD AT BEGINNING OF STRIP
 XDIF   VARIABLE   P6-P3                   X DIST FB TO TREE
 YDIF   VARIABLE   P7-P4                   Y DIST FB TO TREE
 XDIF1  VARIABLE   X$PBX-P3                X DIST FB TO PARTIAL BUNCH
 YDIF1  VARIABLE   X$PBY-P4                Y DIST FB TO PARTIAL BUNCH
 NXDIF  VARIABLE   -X$XDIF                 USED TO CONVERT SIGNED
 NYDIF  VARIABLE   -X$YDIF                      DISTANCE TO MAGNITUDES
*
*
*  * *   OUTPUT TABLES FOR FELLER BUNCHER
 FBTIM  TABLE      MP2,0,25,25             OUTPUT TABLES FOR FB
 ACCVL  TABLE      P12,0,500,25            CYCLES
 ACCTR  TABLE      P13,0,1,12
*
 BDIA   TABLE      P11,0,5,30              TABLES OF SKIDDER BUNCHES
 BTRE   TABLE      P13,0,1,25              CREATED
 BVOL   TABLE      P12,0,1000,25
```

```
187.
188.                *  *  *  *  GENERATE FELLER BUNCHER, INITIALIZE ACC HEAD
189.                *                AND ASSIGN ACCUMULATOR AND BUNCH SIZE LIMITS
190.                *
191.    24   ACCFB  GENERATE    ,,,1,10,15
192.                *
193.    25    INIT  ASSIGN      11,0                 INITILIZE ACCUMULATOR HEAD
194.    26          ASSIGN      12,0
195.    27          ASSIGN      13,0
196.    28          MARK        2                    MARK START OF CYCLE
197.    29          SAVEVALUE   ACCLM,V$ACCLM        MAXIMUM ACC LOAD
198.    30          SAVEVALUE   BUNLM,V$BUNLM        MAXIMUM BUNCH SIZE
199.                *
200.                *
201.                *
202.                *  *  *  *  TREE     CREATE NEXT TREE
203.                *
204.    31    TREE  ASSIGN      5+,1                 TREE NUMBER
205.    32          ASSIGN      6,V$XCORD            X COORDINATE OF TREE
206.    33          ASSIGN      7,V$YCORD            Y COORDINATE OF TREE
207.    34          ASSIGN      8,V$TDIAM            DBH OF TREE
208.                *
209.                *
210.                *
211.                *  *  *  *  ? IS TREE IN A NEW STRIP ?   IF NOT GO TO OLDST
212.                *                IF A NEW STRIP - REASSIGN Y CORD AND MARK END OF
213.                *                STRIP P10
214.                *
215.                      TEST G      P7,X$STPLN,OLDST        ? NEW STRIP ?
216.    35                ASSIGN      7,V$NEWY             NEW Y COORD
217.    36                ASSIGN      10,1                 END OF STRIP INDICATOR
218.    37                TRANSFER    ,ACCFL
219.                *
220.                *
221.                *
222.                *  *  *  *  OLDSTP - THE FB DID NOT MOVE TO A NEW STRIP.  SEE IF THERE IS
223.                *                ROOM IN ACC HEAD FOR ANOTHER TREE - IF SO SEE HOW FAR
224.                *                AWAY TREE IS.
225.                *
226.    39   OLDST  TEST L      P13,X$ACCLM,ACCFL       IF ACCHEAD FULL - GO TO ACCFL
227.                *
228.    40   TDIST  SAVEVALUE   XDIF,V$XDIF          CALCULATE DISTANCE TO TREE
229.    41          TEST L      X$XDIF,0,DTST1
230.    42          SAVEVALUE   XDIF,V$NXDIF
231.    43   DTST1  SAVEVALUE   YDIF,V$YDIF
232.    44          TEST L      X$YDIF,0,DTST2
233.    45          SAVEVALUE   YDIF,V$NYDIF
234.    46   DTST2  SAVEVALUE   MAX,X$XDIF
235.    47          SAVEVALUE   MIN,X$YDIF
236.    48          TEST L      X$MAX,X$MIN,DTST3
237.    49          SAVEVALUE   MIN,X$XDIF
238.    50          SAVEVALUE   MAX,X$YDIF
239.    51   DTST3  ASSIGN      9,X$MAX
240.    52          TEST G      X$MIN,0,FIRST
241.    53          ASSIGN      9,V$HYP              DIST FROM FB TO TREE
                    *
```

```
                *  *  *  *   FIRST   IF THIS IS THE FIRST TREE IN THE ACCUMULATOR
                *                     GO TO FELL AND FELL THE TREE.    IF IT IS NOT
                *                     THE FIRST TREE SEE HOW FAR AWAY THE TREE IS.
                *                     IF TOO FAR GO TO ACCFL - THIS IS A COMPLETE LOAD
                *
     54          FIRST TEST G        P11,0,FELL          ? IF FIRST TREE ?
     55                TEST L        P9,X$ADLIM,ACCFL ? TREE TOO FAR?
                *
                *
                *  *  *  *   FELL      FELLER BUNCHER TRAVELS TO TREE AND FELLS IT
                *                     ADDS TREE TO ACCUMULATOR HEAD AND RECORDS PRODUCTION
                *                     DATA. THEN FB LOOKS AT NEXT TREE
                *
     56          FELL  QUEUE           FBTRV
     57                ADVANCE         V$FBTRV             FELLER TRAVELS TO TREE
     58                DEPART          FBTRV
     59                ASSIGN          4,P7                TREE COORDINATES BECOME
     60                ASSIGN          3,P6                FB COORDIANATES
     61                QUEUE           FBSHR
     62                ADVANCE         V$FBSHR             FB SHEARS TREE
     63                DEPART          FBSHR
                *
                *                                         FB ADDS TREE TO ACC HEAD
     64                ASSIGN          11+,P8              SUM OF DIA
     65                ASSIGN          13+,1               NO OF TREES
     66                ASSIGN          12+,V$TVOL          TOTAL LOAD VOL
                *
     67                SAVEVALUE       FBTRE+,1            RECORD PRODUCTION OF FELLER
     68                SAVEVALUE       FBVOL+,V$TVOL
     69                SAVEVALUE       FBDIS+,P9
     70                TRANSFER        ,TREE
                *
                *
                *  *  *  *   ACCFL  - ACCUMULATOR FULL
                *                     ? HAS A PARTIAL BUNCH BEEN STARTED ?
                *                     IF NO PARTIAL BUNCH GO TO DROP-DROP TREES AT CURRENT LOCATION.
                *                     IF THERE IS A PARTIAL BUNCH SEE HOW FAR AWAY IT IS
                *
     71          ACCFL TEST G        X$PBDIA,0,DROP      HAS A PARTIAL BUNCH BEEN STARTED?
                *                                         IF NOT - GO TO DROP
     72                SAVEVALUE     XDIF,V$XDIF1        CALCULATE DISTANCE FROM FB
     73                TEST L        X$XDIF,0,DTSTA      TO PARTIAL BUNCH
     74                SAVEVALUE     XDIF,V$NXDIF
     75          DTSTA SAVEVALUE     YDIF,V$YDIF1
     76                TEST L        X$YDIF,0,DTSTB
     77                SAVEVALUE     YDIF,V$NYDIF
     78          DTSTB SAVEVALUE     MAX,X$XDIF
     79                SAVEVALUE     MIN,X$YDIF
     80                TEST L        X$MAX,X$MIN,DTSTC
     81                SAVEVALUE     MAX,X$YDIF
     82                SAVEVALUE     MIN,X$XDIF
     83          DTSTC ASSIGN        9,X$MAX
     84                TEST G        X$MIN,0,PBFAR
     85                ASSIGN        9,V$HYP                    DISTANCE FB TO PARTIAL BUNCH
                *
                *
                *  *  *  *   PBFAR   PARTIAL BUNCH TOO FAR?
                *                     IF P BUNCH IS NOT TOO FAR AWAY TRAVEL TO  PARTIAL
                *                     BUNCH-TRVPB AND DROP LOAD, IF IT IS TOO FAR
                *                     START NEW BUNCH RIGHT HERE, SEND AN OFFSPRING OF SPLIT BLOCK
                *                     OVER TO MAKE LAST PARTIAL BUNCH COMPLETE
```

```
                86   PBFAR TEST G     P9,XSBDLIM,TRVPB   IS PARTIAL BUNCH TOO FAR ?
                     *
                87         PRIORITY   16
                88         SPLIT      1,BUNCH           OFFSPRING GOES TO MAKE LAST BUNCH
                89         PRIORITY   10                COMPLETE WHILE FB DROPS TREES
                90         BUFFER                       HERE AND STARTS NEW BUNCH
                91         TRANSFER   ,DROP
                     *
                     *
                     *
                     * * * * TRVPB - TRAVEL TO PARTIAL BUNCH
                     *
                92   TRVPB QUEUE      FBTRV
                93         ADVANCE    V$FBTRV           FB TRAVELS TO PART BUNCH
                94         DEPART     FBTRV
                95         ASSIGN     3,X$PBX           PB COORDINATES BECOME FB COORDINATES
                96         ASSIGN     4,X$PBY
                97         SAVEVALUE  FBDIS+,P9
                     *
                     * * * * DROP -    FELLER DROPS TREES IN ACC HEAD
                     *                 EITHER ADDING TO EXISTING PARTIAL BUNCH OR
                     *                 STARTING A NEW BUNCH
                     *
                98   DROP   QUEUE      FBDRP
                99          ADVANCE    V$FBDRP           DROP TREES FROM ACC HEAD
               100          DEPART     FBDRP
               101          SAVEVALUE  PBDIA+,P11        TOTAL SUM OF DIAM IN BUNCH
               102          SAVEVALUE  PBTRE+,P13        TOTAL NUMBER OF TREES
               103          SAVEVALUE  PBEND,P10         STRIP END INDICATOR
               104          SAVEVALUE  PBVOL+,P12        TOTAL VOL
               105          SAVEVALUE  PBX,P3            X COORD OF BUNCH
               106          SAVEVALUE  PBY,P4            Y COORD OF BUNCH
                     *
                     * * *    DELAY    IF A DELAY IS TO OCCUR IT HAPPENS HERE
               107          QUEUE      MCDLY
               108          ADVANCE    V$MCDLY           MECHANICAL DELAY
               109          DEPART     MCDLY
               110          QUEUE      NMDLY
               111          ADVANCE    V$NMDLY           NONMECHANICAL DELAY
               112          DEPART     NMDLY
                     * * *                  CHECK IF TIME FOR BREAK
               113          QUEUE      BREAK
               114          GATE LS    COFFE,NOBRK       CHECK IF BREAK TIME
               115          ADVANCE    1500              IS MIN COFFEE BREAK
               116          LOGIC R    COFFE
               117   NOBRK  GATE LS    LUNCH,QUIT        CHECK IF LUNCH TIME
               118          ADVANCE    3000
               119          LOGIC R    LUNCH
```

```
                * * *  QUIT - TABULATE TIME ON BREAKS AND CHECK IF ITS TIME TO QUIT
                *
 120    QUIT    SAVEVALUE   FBTIM+,MP2          TABULATE CYCLE TIME
 121            DEPART      BREAK
                *
 122            SAVEVALUE   FBACC+,1            KEEP TRACK OF NUMBER OF ACC LOADS
 123            TABULATE    FBTIM               TABULATE TIME AND PRODUCTION
 124            TABULATE    ACCVL
 125            TABULATE    ACCTR
 126            GATE LS     DAY                 IF SHIFT IS OVER, STOP TIL TOMORROW
                *                               REINITILIZE ACC HEAD
 127            MARK        2                   MARK START OF CYCLE
 128            ASSIGN      11,0
 129            ASSIGN      12,0
 130            ASSIGN      13,0
 131            ASSIGN      10,0
 132            MARK        2
 133            SAVEVALUE   ACCLM,V$ACCLM       SET NEW ACC HEAD LIMIT
                *
                *
                * * * *  ? IS THIS A COMPLETE BUNCH OR THE END OF A STRIP ?
                *                 IF SO GO TO BNCOM TO COLLECT BUNCH DATA
                *                 IF NOT A COMPLETE BUNCH
                *                 OR THE END OF A STRIP - GO BACK TO FELL NEXT TREE
                *
 134            TEST L      X$PBDIA,X$BUNLM,BNCOM  IS BUNCH COMPLETE ?
 135            TEST G      X$PBEND,0,TDIST        IS IT THE END OF A STRIP ?
                *
                *
                *
                * * * * BNCOM - BUNCH COMPLETE  OFFSPRING GOES TO COMPLETE
                *                 BUNCH WHILE PARENT -FELLER BUNCHER- GOES TO CUT NEXT TREE
                *
 136    BNCOM   PRIORITY    16
 137            SPLIT       1,BUNCH
 138            PRIORITY    10
 139            BUFFER
 140            TEST GE     X$PBEND,1,TDIST    IF END OF STRIP
 141            ASSIGN      4,P7               CORRECT DISTANCE TO NEW STRIP
 142            ASSIGN      3,P6
 143            ASSIGN      3+,X$MVSTP         ADD DISTANCE BETWEEN STRIPS
 144            TRANSFER    ,TDIST
                *
```

```
398.                *  *  *  *   BUNCH =   BUNCH IS DESIGNATED COMPLETE AND READY
399.                *                        FOR SKIDDER TO PICK UP
400.                *
401.                *                     BUNCH IS CONSIDERED COMPLETE WHEN IT IS BIG
402.                *                      ENOUGH FOR THE SKIDDER, OR IF P BUNCH IS TOO FAR
403.                *                      FROM FELLER BUNCHER,OR FELLER BUNCHER HAS
404.                *                      REACHED THE END OF A STRIP
405.                *
406.          145    BUNCH SAVEVALUE   BNCOM+,1                 MAKE P BUNCH XTION INTO ACTIVE XTION
407.                *
408.          146          ASSIGN      12,X$PBVOL               VOLUME OF BUNCH
409.          147          ASSIGN      11,X$PBDIA               SUM OF DIAM
410.          148          ASSIGN      13,X$PBTRE               TOTAL NUM OF TREES
411.          149          ASSIGN      4,X$PBY                  Y COORD DOWN STRIP
412.                *
413.          150          SAVEVALUE   PBDIA,0                  REINITIALIZE PARTIAL BUNCH
414.          151          SAVEVALUE   PBTRE,0
415.          152          SAVEVALUE   PBVOL,0
416.          153          SAVEVALUE   BUNLM,V$BUNLM            SET BUNCH LIMIT
417.                *
418.                *                                           RECORD BUNCH PRODUCTION
419.          154          TABULATE    BDIA
420.          155          TABULATE    BTRE
421.          156          TABULATE    BVOL
422.          157          TERMINATE
423.                *  *  *  *  *  *  INPUT DATA
424.                *
425.                *
426.                 FBTRV FVARIABLE   P9*100/V$SPEED           TRAVEL TIME (DIST/SPEED) IN CENTIMIN
427.                *                                          P9 = DISTANCE
428.                 SPEED FVARIABLE   X$FTRV1+X$FTRV2*FN$SNORM/10    TRAVEL SPEED
429.                 FBSHR FVARIABLE   X$FSHR1+X$FSHR2*FN$SNORM/10    POSITION AND SHEAR TIME
430.                 FBDRP FVARIABLE   X$FDRP1+X$FDRP2*FN$SNORM/10    SWING AND DROP TIME
431.                *
432.                 ACCLM FVARIABLE   X$ACLM1                        MAX ACC LOAD  NUM OF TREES
433.                 BUNLM FVARIABLE   X$BNLM1                        MAX BUNCH SIZE = SUM OF DIA
434.                *
435.                 XCORD FVARIABLE   (X$STPWH+1)*RN3/1000   X COORDINATE OF TREE
436.                 YCORD FVARIABLE   FN$YCDIF+P7            Y COORDINATE OF TREE
437.                 TDIAM FVARIABLE   FN$DBH                 DIAMETER OF TREE
438.                 TVOL  FVARIABLE   (186*P8*P8-283)/10      TREE VOL IN TERM OF DIA(P8)
439.                *                                          .01 CU FT
440.                 MCDLY FVARIABLE   FN$MCDLY               MECHANICAL DELAY
441.                 NMDLY FVARIABLE   FN$NMDLY               NON-MECHANICAL DELAY
442.                *
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444.          * * * * *  DEFINING FUNCTIONS
445.          *
446.          *      THIS INPUT DATA WAS OBTAINED FROM TIME STUDIES CARRIED OUT IN 1974
447.          *
448.           YCDIF FUNCTION   RN3,D10                    YDIST FROM CURRENT TREE TO NEXT TREE
449.          ,18,0/.48,2/.64,4/.76,6/.84,8/.88,10/.92,12/.95,14/.98,16/1.,18
450.          *
451.          *
452.           DBH   FUNCTION   RN4,C11                    DIAMETER DISTRIBUTION
453.          0,2/.254,4/.497,6/.783,8/.869,10/.932,12/.964,14/.984,16/.995,18/.999,20
454.          1.0,22
455.          *
456.           NMDLY FUNCTION   RN6,C8                     NON-MECHANICAL DELAY
457.          0,0/.973,0/.982,100/.987,200/.992,500/.996,1000/.999,2000/1.0,5000
458.          *
459.           MCDLY FUNCTION   RN6,C5                     MECHANICAL DELAY
460.          0,0/.994,0/.996,500/.998,1000/1.0,5000
461.          *
462.          * * * * * *  INITIAL CONDITIONS FOR THE STAND
463.          *
464.                 INITIAL    X$AVDBH,510               AVE STAND DBH (IN*100)
465.                 INITIAL    X$AVVOL,284200            STAND VOL (.01 CU FT/ACRE)
466.                 INITIAL    X$AVHGT,60                AVE TREE HEIGHT (FT)
467.                 INITIAL    X$TRPAC,550               TREES/ACRE
468.                 INITIAL    X$STPLN,660               STRIP LENGTH (FT)
469.                 INITIAL    X$STPWH,10                STRIP WIDTH (FT)
470.                 INITIAL    X$MVSTP,32                DISTANCE BETWEEN STRIPS (FT)
471.                 INITIAL    X$LBCFT,55                WOOD DENSITY LB/CU FT - GREEN
472.                 INITIAL    X$WKDAY,8                 HOURS IN A WORK SHIFT
473.          *
474.          * * * * * *  INITIAL CONDITIONS FOR THE RUBBER TIRED FELLER/BUNCHER
475.          *
476.                 INITIAL    X$ADLIM,8                 ACCUMULATOR DISTANCE LIMIT
477.                 INITIAL    X$BDLIM,45                BUNCH DISTANCE LIMIT
478.                 INITIAL    X$FBGPH,47                FUEL CONSUMPTION (GAL PER HR * 10)
479.                 INITIAL    X$FTRV1,150               MEAN TRAVEL SPEED (FT/MIN)
480.                 INITIAL    X$FTRV2,50                ST. DEV. TRAVEL SPEED (FT/MIN)
481.          *
482.                 INITIAL    X$FSHR1,25                MEAN SHEAR TIME (CENT MINUTES)
483.                 INITIAL    X$FSHR2,12                ST. DEV. SHEAR TIME
484.                 INITIAL    X$FDRP1,15                MEAN DROP TIME (CENT MINUTES)
485.                 INITIAL    X$FDRP2,9                 ST. DEV. DROP TIME
486.                 INITIAL    X$ACLM1,5                 MAXIMUM # TREES IN ACC HEAD
487.          *
488.                 INITIAL    X$BNLM1,120               MAX SKIDDER BUNCH -SUM OF DIA (IN)
489.                 INITIAL    X$FBTYP,1                 RUBBER TIRED FELLER BUNCHER CODE
490.          * * * * * *  INITIAL CONDITIONS FOR THE RUN
491.                 RMULT      4,83,151,,701
492.                 START      5,,5,1
493.                 END
```

```
1*            SUBROUTINE SYSTM(IX)
2*            DIMENSION IX(5)
3*            DATA I/0/
4*      C
5*           1 FORMAT(1H1,43X,'FULL TREE FIELD CHIPPING ',/,46X,'NORTH CENTRAL '
6*           A 'SIMULATOR'//1H0,58X,'DEVELOPED BY THE'/1H ,46X,'NORTH CENTRAL '
7*           B,'FOREST EXPERIMENT STATION'/1H ,44X,'FOREST SERVICE U. S. DEP
8*           C,'T. OF AGRICULTURE'//1H0,29X, 'FOREST PRODUCTS MARKETING AND
9*           TUTILIZATION PROJECT, DULUTH, MINNESOTA'/1H ,61X,'AND THE'/1H ,
10*          E40X,'FOREST ENGINEERING LABORATORY, HOUGHTON, MICHIGAN'//1H0,62X
11*          F,'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
12*          G A. WINSAUER, PROGRAMMER'//)
13*     C
14*           2 FORMAT(1H0,'I. STAND CHARACTERISTICS,'//1H0, F12.2,' CU FT. ',
15*           A 'AVERAGE VOLUME'
16*           B' PER ACRE '/1H0,F12.2,' INCHES, AVERAGE DBH,'/1H0,F12.2,' FEET,',
17*           C' AVERAGE TREE HEIGHT,'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
18*           D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
19*     C
20*           3 FORMAT(1H0,'II. SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
21*           A'ANALYST.'//1H ,2X,'A. FELLER-BUNCHER.',10X,'I10,' MACHINE',
22*           B 5X,'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'
23*           C ,//9X,'MACHINE LIMITATIONS '/)
24*     C
25*           4 FORMAT(1H0,'II. SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
26*           A'ANALYST.'//1H ,2X,'A. FELLER-BUNCHER.',10X,'I10,' MACHINE',
27*           B5X,'RUBBER-TIRED TYPE',//,9X,'MACHINE LIMITATIONS. '/)
28*     C
29*           5 FORMAT(1H , 14X, 'THE SHEAR CAN HANDLE ONLY ONE TREE.')
30*     C
31*           6 FORMAT( 1H , 10X, 'THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN',
32*           A ' A LOAD OF UP TO',F6.1,' TREES')
33*     C
34*           7 FORMAT(1H0,8X,'BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:'/
35*           A1H0, 10X,'THE FELLER-BUNCHERS TRY TO ACHIEVE',
36*           B ' SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO',
37*           C F6.1, ' INCHES')
38*     C
39*     C
40*                 X1 = IX(1)
41*                 X2 = IX(2)
42*                 X3 = IX(3)
43*                 X4 = IX(4)
44*                 X5 = IX(5)
45*                 I = I + 1
46*                 IF ( I .GT. 2 ) I = 1
47*                 GO TO (10,20),I
48*     C
49*           10 CONTINUE
50*              AVVOL= X1/100.
51*     C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
52*              AVDBH= X2/100.
53*     C ACDBH = AVERAGE DBH - INCHES
54*              AVHGT=X3
55*     C AVHGT = AVERAGE TREE HEIGTH - FEET
56*              TRPAC=X4
57*     C TRPAC = AVERAGE NUMBER TREES PER ACRE
58*              TRSPC=(43560./TRPAC)**.5
59*     C TRSPC = AVERAGE TREE SPACING - FEET
60*              WRITE (6,1)
61*              WRITE(6,2) AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
62*              RETURN
63*     C
64*           20 CONTINUE
65*              NUMFB=1
66*     C NUMFB = NUMBER OF FELLER-BUNCHERS
67*              ACCLM = X2
68*     C ACCLM ACCUMULATOR LIMIT SUM OF DBH
69*              FBTYP=X3
70*     C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
71*              BUNLM = X4
72*     C  BUNLM  BUNCH SIZE LIMIT
73*              IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
74*              IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
75*              IF (ACCLM .LT. 1.) WRITE(6,5)
76*              IF (ACCLM .GE. 1.) WRITE(6,6) ACCLM
77*              WRITE(6,7) BUNLM
78*              RETURN
79*     C
80*              END
```

```
      SUBROUTINE FELBN (IX)
      DIMENSION IX(5)
      DATA I/0/
      INTEGER FBACC,FBDIS,BNCOM
C
    1 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',///,1H ,132('*'),////
     B//,1H,'I.    A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER(S)'
     1,' INCLUDING'//16X,F8.2,
     2 5X,'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3  5X,'MINUTES MECHANICAL DELAY, ',/,' / 16X,F8.2,
     4 5X,'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER, ',5X,
     D 'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'///)
C
    2 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',///,1H ,132('*'),////
     B//,1H,'I.    A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER'
     1,' INCLUDING'//16X,F8.2,
     2 5X,'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3  5X,'MINUTES MECHANICAL DELAY, ',/,' / 16X,F8.2,
     4 5X,'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER, ',5X,
     D'RUBBER-TIRED TYPE.'///)
C
    3 FORMAT(1H,'II.   A.',I8,5X,'TOTAL ACCUMULATOR CYCLES COMPLETED',
     A' - ALL MACHINES.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' CYCLE.',//,16X,F8.2,5X,'AVERAGE VOLUME PER CYCLE - CU.FT.',/)
C
    4 FORMAT(1H,6X,'B.',I8,5X,'BUNCHES COMPLETED',//,
     A16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER BUNCH.',/)
C
    5 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF CYCLES PER BUNCH.',/)
C
    6 FORMAT(1H,15X,F8.2,5X,'AVERAGE VOLUME PER BUNCH - CU.FT.',//,
     A7X,'C.',I8,5X,'TOTAL TREES FELLED.',//,7X,'D.',F8.1,5X,
     B'TOTAL VOLUME FELLED - CU.FT.',//,7X,'E.',
     CF8.2,5X,'TOTAL TONS FELLED',//,7X,'F.',I8,5X,
     D  'TOTAL DISTANCE TRAVELED - FEET',///)
C
    7 FORMAT(1H,'III.  A.',F8.2,5X,'AVERAGE NUMBER OF CYCLES PER',
     A' MACHINE HOUR.',/)
C
    8 FORMAT(1H,6X,'B.',F8.2,5X,'AVERAGE NUMBER OF BUNCHES COMPLETED',
     A' PER MACHINE HOUR.',//,7X,'C.',F8.2,5X,'AVERAGE NUMBER OF',
     B' TREES FELLED PER MACHINE HOUR.',//,7X,'D.',F8.2,5X,'AVERAGE',
     C' VOLUME FELLED PER MACHINE HOUR.',//,7X,'E.',F8.2,5X,'AVERAGE',
     D' NUMBER OF TONS FELLED PER MACHINE HOUR.',//,7X,'F.',F8.2,5X,
     E'AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.',///)
C
C
   11 FORMAT(1H,'IV.   A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED BY',
     A' THE FELLER-BUNCHER.',//,16X,F8.2,5X,'GALLONS PER HOUR.',//,16
     BX,F8.2,5X,'GALLONS PER TON.',//,16X,F8.2,5X,'GALLONS PER CUNIT.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I+ 1
      IF (I .GT. 3) I = 1
      GO TO ( 10,20,30),I
   10 CONTINUE
      NUMFB = 1
C NUMFB =  NUMB. OF FELLER-BUNCHERS
      FBTYP = X2
C  FELLER-BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
C  BREAK AND DELAY TIMES IN MINUTES
      BREAK=X3/100
      DELAY=X4/100
      DELNM=X5/100
      RETURN
   20 CONTINUE
```

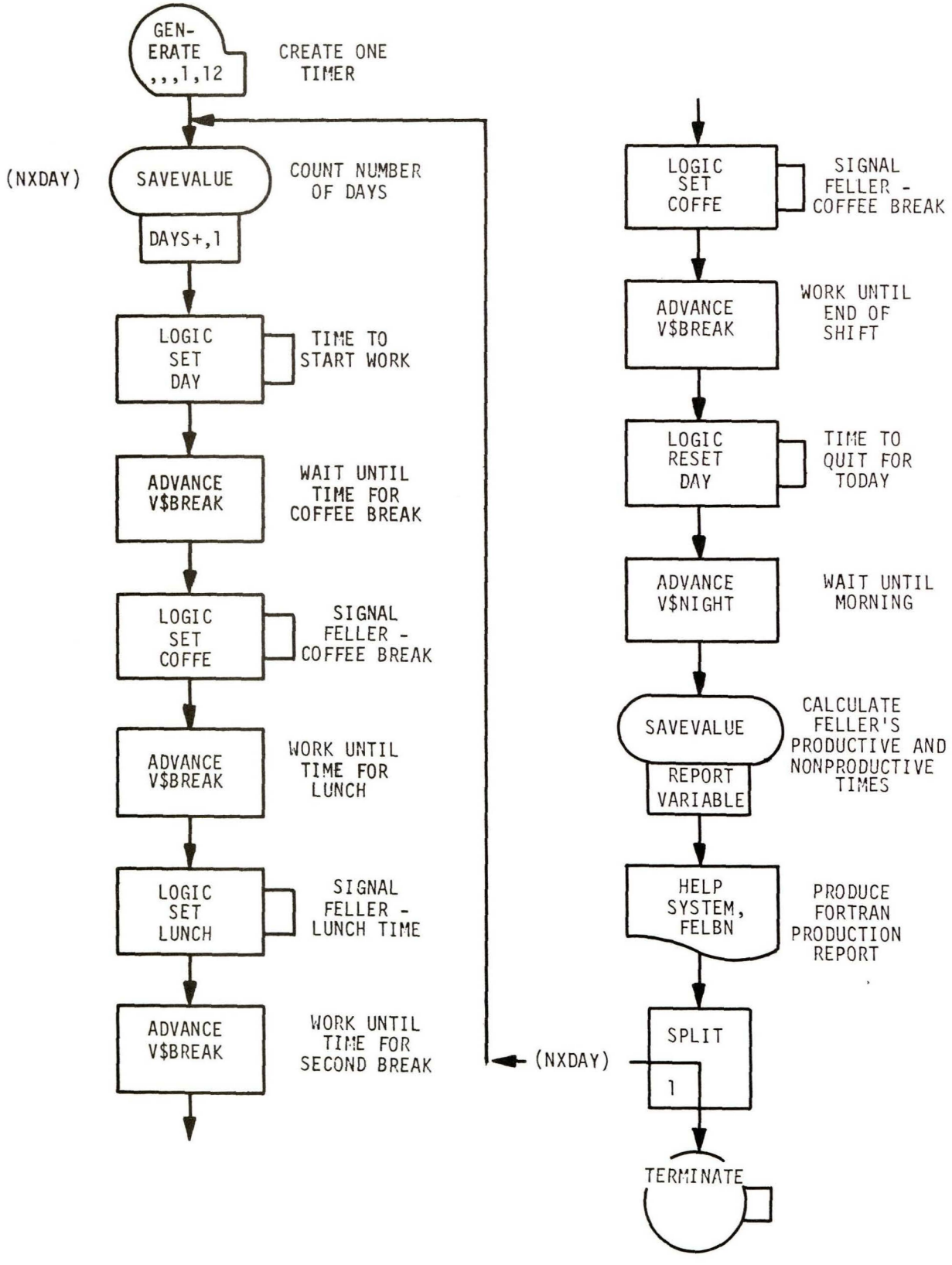
```
75*             NTREE =  X1
76*             FBVOL = X2/100.
77*       C FBVOL =    VOL. FELLED ALL MACHINES
78*             FBCNT = FBVOL/100.
79*       C  FBCNT  FELLER-BUNCHER VOL. IN CUNITS.
80*             BNCOM = X3
81*       C BNCOM =  BUNCHES COMPLETED
82*             FBHR = X4/100.
83*             FBDIS =  X5
84*       C FBDIS =    DIST. TRAV. ALL MACHINES
85*             RETURN
86*          30 CONTINUE
87*             FBACC = X1
88*       C  FBACC  NUMBER OF ACCUMULATOR COMPLETED CYCLES.
89*             XDEN = X2
90*       C  POUNDS OF WOOD PER CUBIC FOOT.
91*             FBTNS = X3*XDEN/200000
92*             FBGPH = X4/10
93*       C  FELLER-BUNCHER TOTAL GALLONS USED
94*       C  FELLER-BUNCHER VOL. IN TONS
95*       C
96*             IF( FBTYP.EQ.0 )WRITE(6,1)FBHR,BREAK,DELAY,DELNM,NUMFB
97*             IF( FBTYP.EQ.1 )WRITE(6,2)FBHR,BREAK,DELAY,DELNM,NUMFB
98*       C
99*             FBTPC = NTREE*1./FBACC
100*      C  FBTPC  TREES PER CYCLE
101*            FBVPC = FBVOL/FBACC
102*      C  FBVPC  VOLUME PER CYCLE
103*            WRITE(6,3)FBACC,FBTPC,FBVPC
104*      C
105*            FBTPB =  NTREE*1./BNCOM
106*      C FBTPB =  AVE. TREES PER COMPLETED BUNCH.
107*            WRITE(6,4)BNCOM,FBTPB
108*      C
109*            FBCPB = FBACC*1./BNCOM
110*            WRITE(6,5)FBCPB
111*      C
112*            FBVPB = FBVOL/BNCOM
113*      C FBVPB =  AVE. VOL. PER BUNCH
114*            WRITE (6 ,6) FBVPB,NTREE,FBVOL,FBTNS,FBDIS
115*      C
116*            CYCHR = FBACC/FBHR
117*            WRITE(6,7)CYCHR
118*      C
119*            FBBMH = BNCOM/FBHR
120*      C FBBMH = AVE. BUNCHES PER MACHINE HOUR
121*            FBTMH = NTREE/FBHR
122*      C FBTMH = TREES FELLED PER MACHINE HOUR
123*            FBVMH = FBVOL/ FBHR
124*      C FBVMH = VOL. FELLED PER MACHINE HOUR
125*            FBATH = FBTNS/FBHR
126*      C  FBATH  AVERAGE TONS PER HOUR
127*            FBDMH = FBDIS/FBHR
128*      C FBDMH = DIST. TRAV. PER MACHINE HOUR
129*            WRITE (6 ,8) FBBMH,FBTMH,FBVMH,FBATH,FBDMH
130*      C
131*      C  FELLER-BUNCHER GALLONS/HOUR
132*            FBGPT = FBGPH/FBATH
133*      C  FELLER-BUNCHER GALLONS PER TON
134*            FBGPC = FBGPH/(FBVMH/100)
135*      C  FELLER-BUNCHER GALLONS PER CUNIT
136*            FBTGU = FBGPH*FBHR
137*            WRITE(6,11)FBTGU,FBGPH,FBGPT,FBGPC
138*            RETURN
139*            END
```

APPENDIX C

COMPLETE FLOW CHARTS

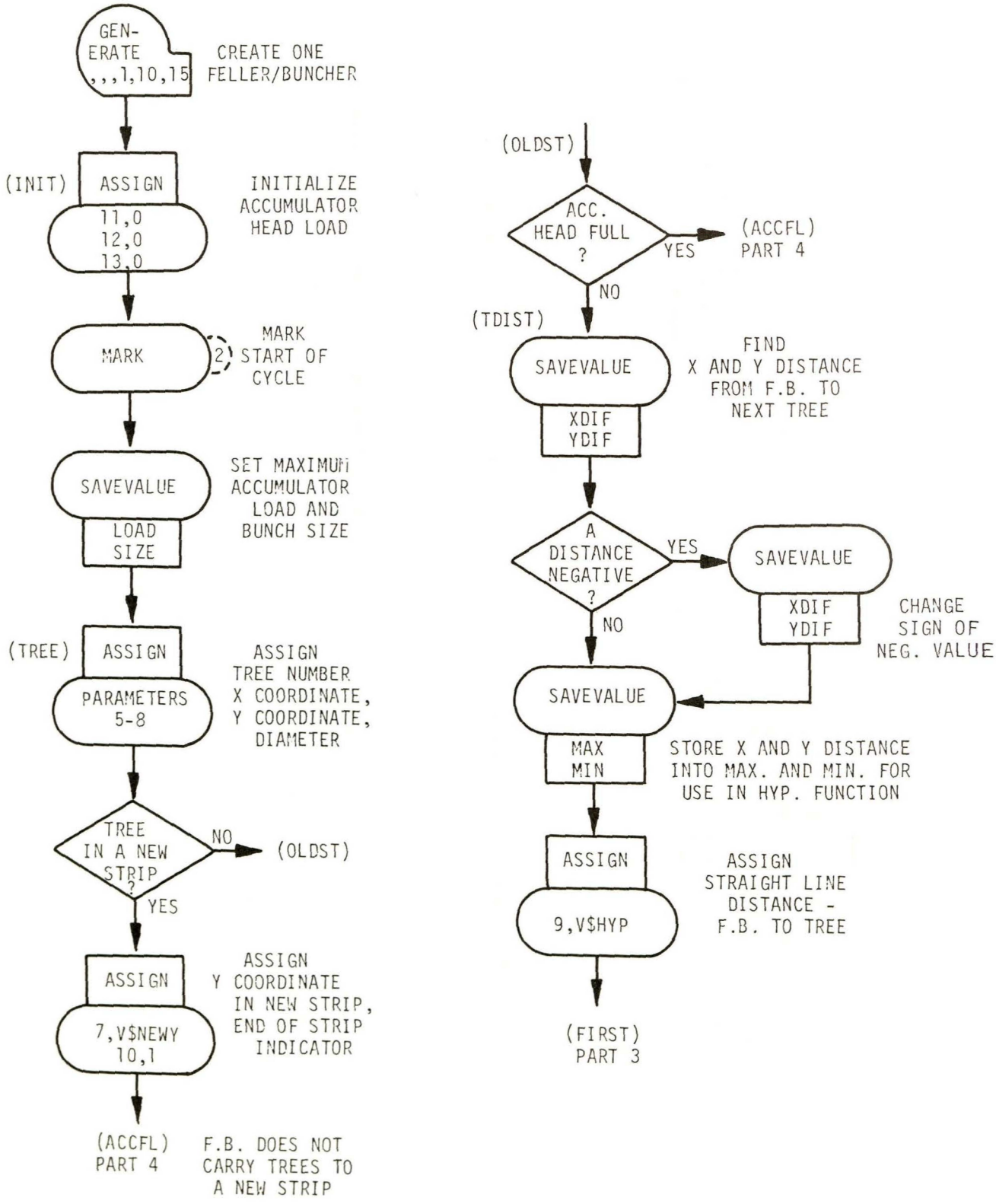
COMPLETE FLOW CHARTS - PART 1 OF 6

TIMER SEGMENT



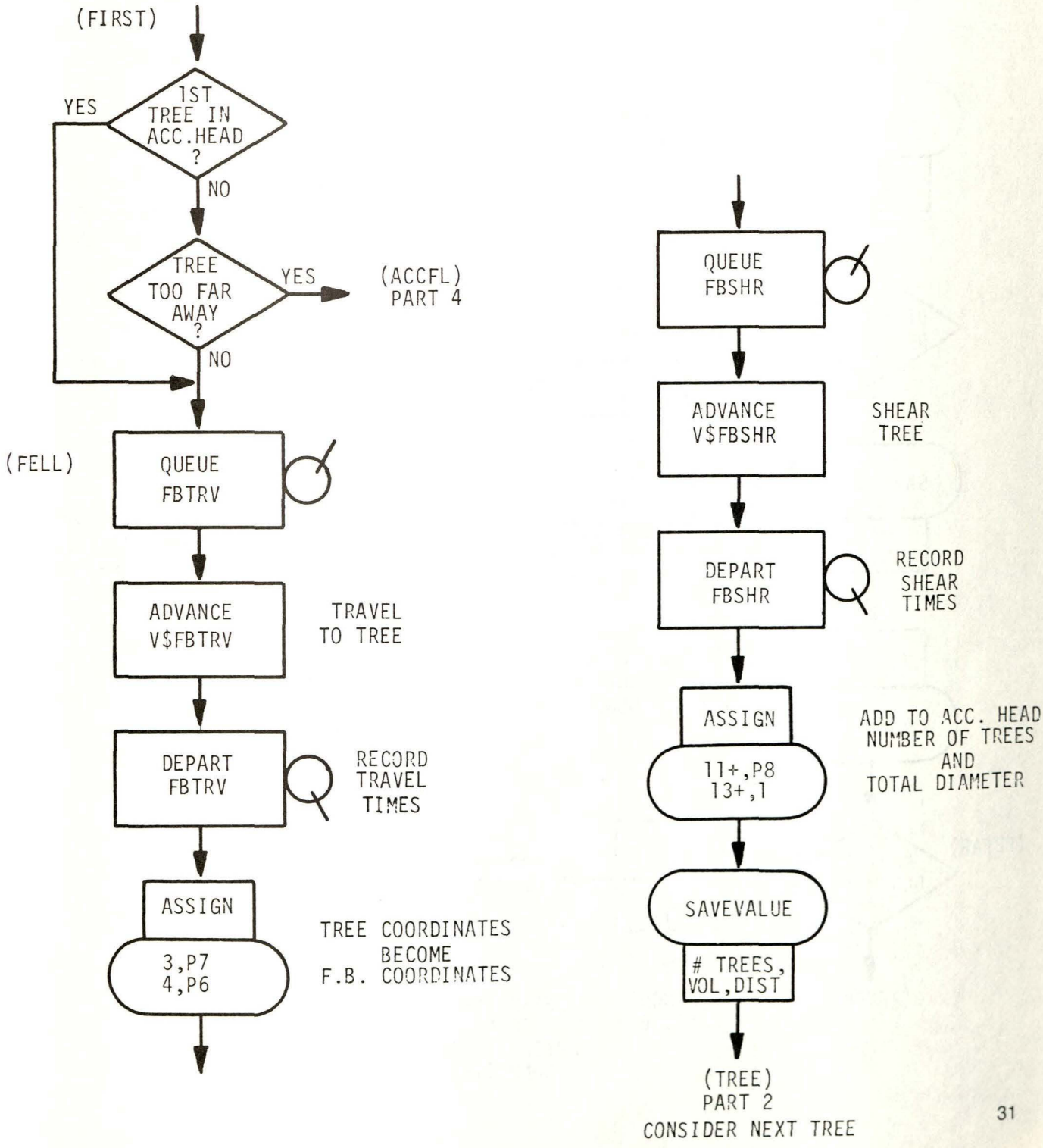
COMPLETE FLOW CHARTS - PART 2 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



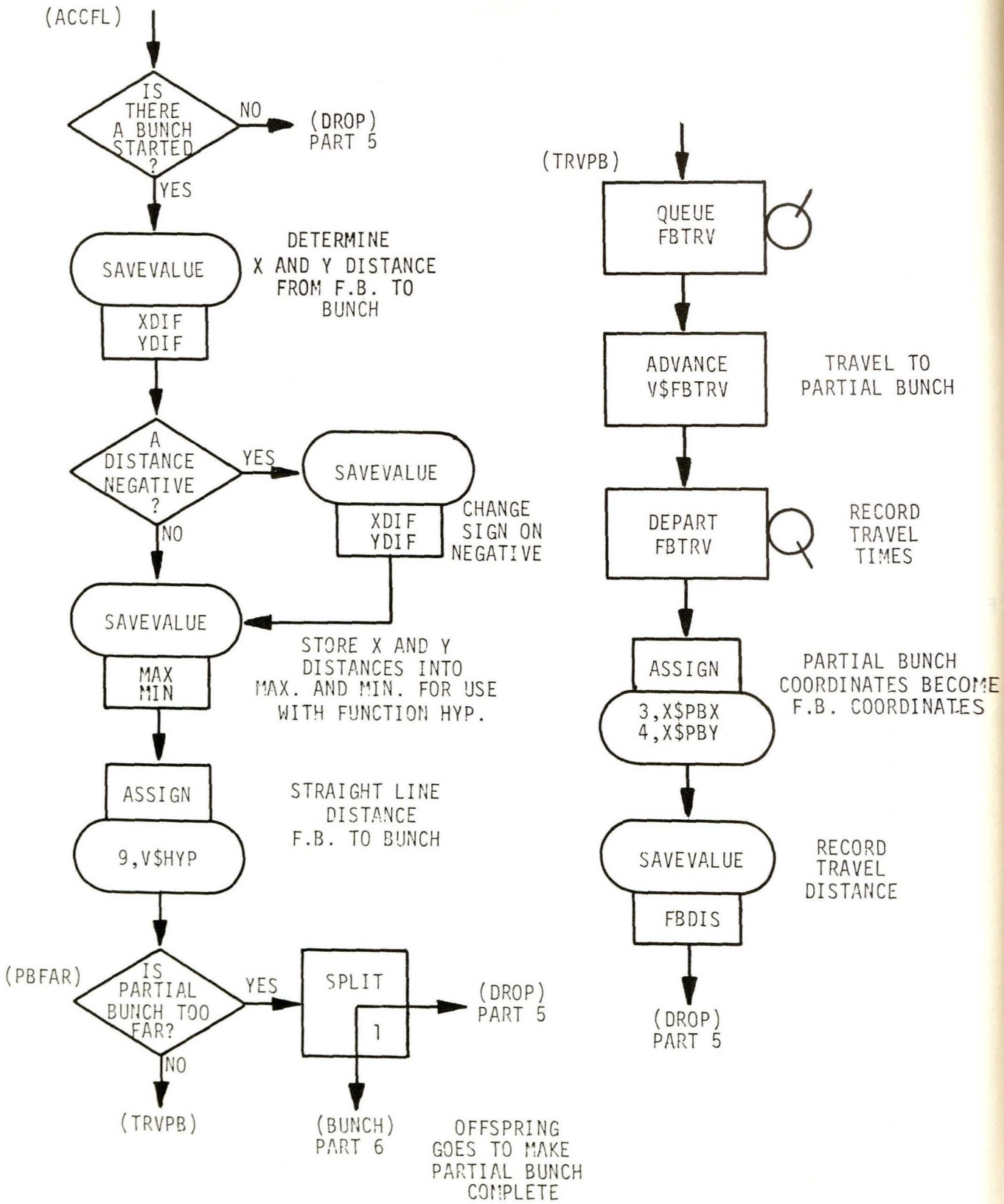
COMPLETE FLOW CHARTS - PART 3 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



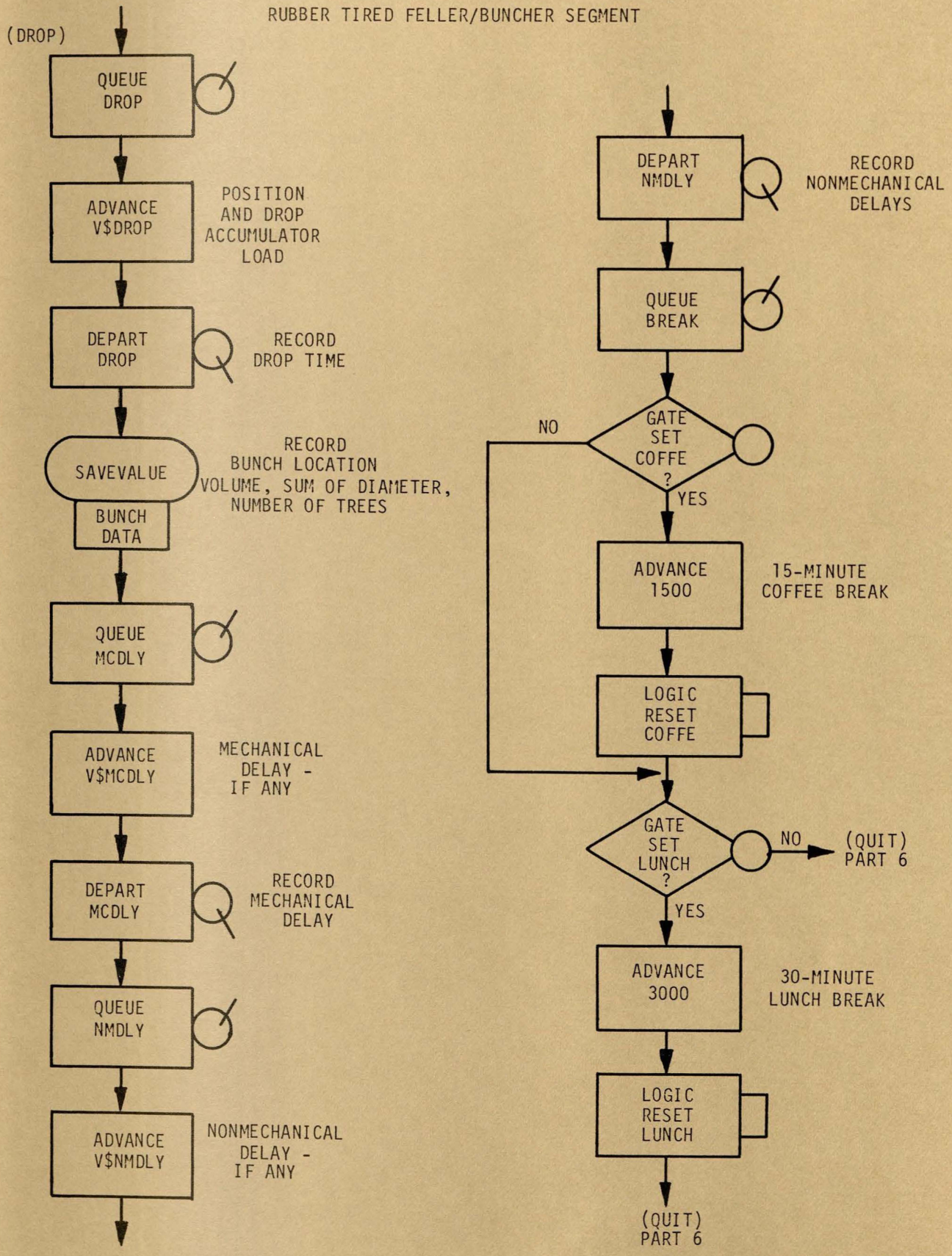
COMPLETE FLOW CHARTS - PART 4 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



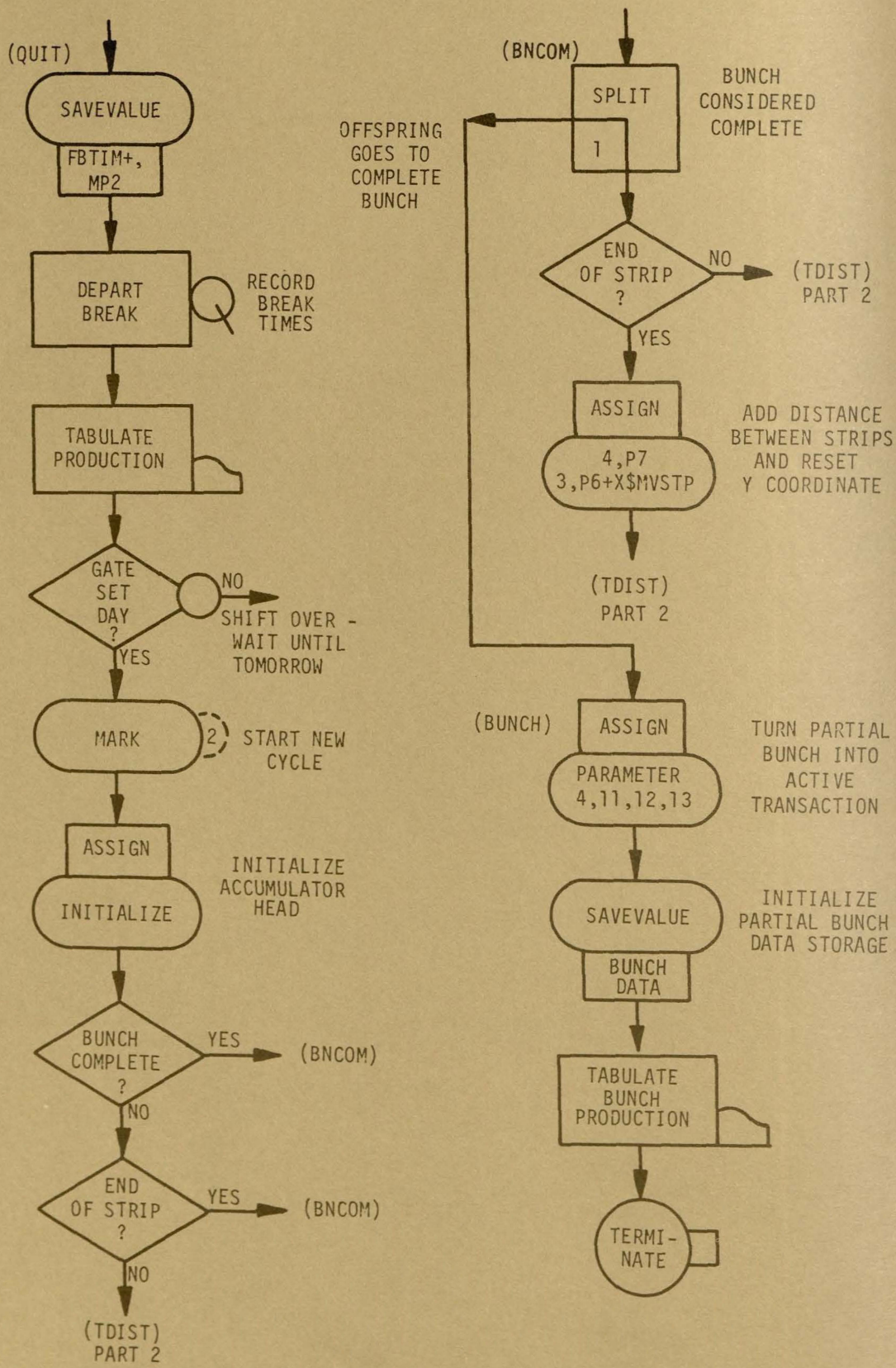
COMPLETE FLOW CHARTS - PART 5 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



COMPLETE FLOW CHARTS - PART 6 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



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